National Science Foundation
Directorate for Geosciences

GEO
Science Plan

FY 1998-2002

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As geoscientists prepare to move into the 21st Century, important and challenging research and educational opportunities confront us. Dramatic advances over recent decades in knowledge about the dynamics of the Earth and its many component parts highlight the contributions that geoscientists can make toward increasing understandings and addressing important societal problems. Those advances also highlight the need to further expand fundamental knowledge about the world in which we live among geoscientists and all other citizens.

In order to determine how it can best advance scientific knowledge, the Directorate for Geosciences (GEO) at the National Science Foundation (NSF) engages in a long-range planning process that evaluates opportunities and needs for geoscience research, infrastructure, and education. This planning process relies on frequent communications among GEO staff and the geoscience research and education communities. This document is the *GEO Science Plan*, a document comparable to long-range plans of previous years because it describes the general priorities for future investments based on scientific opportunities and needs.

GEO's long-range planning for the period from Fiscal Years 1998 through 2002 is based on a number of assumptions. The amount of funding annually available to GEO is not anticipated to be significantly different from the budgetary levels for Fiscal Years 1995 through 1997. Funding pressures on GEO will intensify if other federal agencies that support geoscience research experience budgetary reductions, because the number of geoscientists seeking financial support is expected to remain relatively constant over the planning period.

The active involvement of the geoscience research and education communities in GEO's long-range planning process is manifest in the active role that the Advisory Committee for Geosciences (AC/GEO) has played in the preparation and review of this document. AC/GEO consists of sixteen leading researchers and educators from the broad range of geoscience disciplines and a variety of institutional settings, including academia, government, and the private sector. AC/GEO members endorse this science plan and urge all those with interests in the geosciences to review this science plan and contribute to the development of updated plans in future years.

Robert W. Corell
Assistant Director for Geosciences

William P. Bishop
Chair, Advisory Committee for Geosciences

GEO SCIENCE PLAN, FY 1998-2002

From the earliest days of the human experience, people sought to learn more about the Earth they inhabited. Their motivations for expanding their knowledge were many, ranging from the search for resources that would sustain their lives and a desire to reduce harm from natural disasters to the simple wish to comprehend the beauty of the land, sky, and waters that surrounded them. Modern occupants of the planet are motivated by the same general concerns, although the foundations of our knowledge are greater and the problems we confront take different forms. We still seek to know more about resources, but our attention increasingly turns toward improving our understanding of the processes that affect a diverse array of life forms and the quality of such essential resources as the water we drink and the air we breathe. In a similar way, we now have greater understanding about the mechanisms that result in earthquakes, volcanoes, intense storms, tsunamis, and other catastrophic events, but we need additional knowledge if we are to improve our capabilities for predicting the timing and severity of such events, thereby reducing the loss of life and property. The Directorate for Geosciences at the National Science Foundation seeks to support the ongoing search for new knowledge about the Earth.

I. THE CONTEXT AND PROCESS OF GEO LONG-RANGE PLANNING

> *The National Science Foundation is a catalyst for progress through investment in science, mathematics, and engineering. Guided by its long-standing commitment to the highest standards of excellence in the support of discovery and learning, NSF pledges to provide the stewardship necessary to sustain and strengthen the Nation's science, mathematics, and engineering capabilities and to promote the use of those capabilities in service to society.*

With these words in its strategic plan, *NSF in a Changing World*, the National Science Foundation outlined its vision for a course of action consistent with its efforts since it was established in 1950. To guide the pursuit of this vision, the NSF strategic plan highlights three long-range goals for the agency:

- *Enable the U.S. to uphold a position of world leadership in all aspects of science, mathematics, and engineering.* This goal calls for the development and maintenance of exceptional capabilities in all aspects of science.
- *Promote the discovery, integration, dissemination, and employment of new knowledge in service to society.* This goal encourages enhanced linkages between those who generate new knowledge and those who can use that knowledge in ways that benefit the nation.
- *Achieve excellence in U.S. science, mathematics, engineering, and technology education at all levels.* This goal aims to improve the scientific understanding of all Americans, to enable the nation's workforce to become more scientifically and technologically adept, and to improve the quality of education and training for future scientists.

The NSF plan also identified four core strategies as means through which the agency works to attain its goals:

- *Develop intellectual capital.* Through this strategy, NSF tries to enable a diverse mix of the most capable people to scientifically pursue their most promising ideas in ways that contribute both to the generation of new knowledge and to the enhancement of the scientists as individuals and as members of productive teams.
- *Strengthen the physical infrastructure.* This strategy recognizes the need for U.S. scientists to have access to facilities, equipment, instruments, and other items necessary to engage in successful research and educational efforts.
- *Integrate research and education.* This strategy calls for a more conscious linking of research and educational efforts by U.S. scientists and better communication of the methods and findings of scientific research to a broader audience.
- *Promote partnerships.* This strategy recognizes the need for NSF to work with numerous groups and individuals in order to attain its goals.

The Directorate for Geosciences (GEO) shares the broad vision, goals, and strategies of NSF. Working in concert with other NSF units, with other federal agencies, with international partners, and with numerous other organizations, GEO seeks to make the strongest possible contribution to the advancement of the geosciences in the U.S. and the rest of the world. GEO's long-range planning process seeks to identify the most effective ways that GEO can target its investments and activities in order to fulfill its mission: **To advance scientific knowledge about the solid earth, freshwater, ocean, atmosphere, and geospace components of the integrated Earth system through support for high-quality research, through sustenance and enhancement of scientific capabilities, and through improved geoscience education.**

In order to fulfill its mission, GEO strives to attain three strategic goals:

- **Advance fundamental knowledge about the Earth system.** Meeting this goal requires GEO to maintain strong bases of support across all geoscience fields in order to have the flexibility to respond to the highest-quality research identified by investigators while also identifying opportunities where more focused support can play an especially strong catalytic role in advancing scientific progress. This goal directly supports the NSF goals of upholding world scientific leadership and employing knowledge in service to society through the core strategies of developing intellectual capital and promoting partnerships.
- **Enhance the infrastructure for the conduct of geoscience research.** Meeting this goal requires GEO to identify and make investments in facilities and instruments that will be used by a large number of geoscientists. It also calls for GEO to facilitate interdisciplinary and international collaborations necessary to accomplish the highest-quality scientific projects, and it requires GEO to pursue productive partnerships with other parts of NSF, with other federal agencies, with organizations outside the federal government, and with international partners both to conduct these projects and to disseminate their results. GEO's pursuit of this strategic goal directly supports the NSF goals of upholding world scientific leadership and employing knowledge in service to society through the core strategies of strengthening the infrastructure and promoting partnerships.
- **Improve the quality of geoscience education and training.** To meet this goal, GEO will advance education and training for current geoscientists, facilitate the best education and training for future generations of geoscientists drawn from all segments of the population, and improve knowledge about the integrated components of the Earth system by all people. GEO's pursuit of this strategic goal directly supports the NSF goal of achieving excellence in science education through the core strategies of developing intellectual capital and integrating research and education.

In order to pursue these goals, GEO works with other organizations that have similar interests. Many of GEO's partnerships are with other units in NSF and other federal agencies; other partnerships are with non-governmental organizations. GEO will maintain and strengthen its domestic partnerships during the period from FY 1998 to 2002, and it will look to build up its partnerships with scientists and scientific organizations in other nations. International partnerships will be fostered through a diverse range of mechanisms ranging from assistance for collaborative activities bringing together U.S. and foreign scientists to support for multinational programs and organizations, such as the Ocean Drilling Program (ODP), the International Continental Scientific Drilling Program (ICDP), the World Meteorological Organization (WMO), the World Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP), and the Inter-American Institute for Global Change Research (IAI). GEO commits itself to implement and maintain partnerships based on shared goals and the development of mechanisms for working together that enable more progress to be made than would have been possible had the partners operated independently.

The *GEO Science Plan* outlines the strategies that GEO will pursue to achieve its scientific goals over the five-year planning period from FY1998 to FY 2002. Each of the next three sections focuses on one of GEO's three strategic goals. Within these chapters, special sidebars describe examples of advances that have been possible through GEO's partnerships with other organizations. A final section identifies activities that GEO will undertake if additional resources become available to GEO and its partners.

II. HIGH-PRIORITY RESEARCH ACTIVITIES

The dawn of a new century will be an exciting time for the geosciences. Advances in theory, methods, and infrastructure over recent decades have spurred discoveries regarding the Earth. Although much new knowledge has been generated, many important questions remain unanswered. By helping to answer these questions, geoscientists can continue the process of building the fundamental knowledge base, and in doing so, help to address many critical issues that confront our society. This science plan emphasizes the major scientific issues that constitute the most promising opportunities for geoscientists to make contributions in the coming years. GEO will support these efforts through both disciplinary programs and through a diverse range of complementary special activities.

Fundamental Earth System Processes

When viewed as a system, the Earth consists of a set of distinct yet interacting components. Many geoscientists focus their attention on one of these major components, adding considerably through their work to understandings about how those components function. A first set of critical geoscience research issues correspond to these major components of the Earth system.

Upper Atmospheric Processes

The solar wind and ionizing solar radiation can damage satellites, disrupt communications, and instigate power failures. The zone of the upper atmosphere and beyond where the complex interactions between the solar wind and the Earth occur is called "geospace" and it is the home of "space weather." As our society grows more dependent on advanced technology systems, it becomes more vulnerable to space weather. An ever-increasing number of problems afflicting the modern technological infrastructure can be directly linked to disruptive space weather events.

Research in the area of the upper atmosphere and geospace is supported by disciplinary programs in aeronomy, magnetospheric physics, and solar-terrestrial interactions. Recent research ranges from trying to understand red sprites and blue jets, which are electrical discharges between the upper atmosphere and the ionosphere, to theoretical efforts to predict the causes of major solar storms, such as coronal mass ejections.

In the near term, GEO and other NSF units will place a special emphasis on the National Space Weather Program (NSWP), a cooperative program to achieve an interagency system to provide timely, accurate, and reliable space environment observations, analyses, and forecasts within the next ten years. The NSWP is a partnership between NSF, the Department of Defense (DOD), the Department of Energy (DOE), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the Department of Interior (DOI). NSF's role will be to support the basic research required to underpin a future predictive space weather warning system. Fundamental research on these upper atmospheric or space environment processes will be especially critical in the next five years because of the expected increases in the number of solar storms as the next solar maximum is neared in the period from 2000 to 2002.

Infrastructure support for conducting research on upper atmospheric processes includes the set of high power incoherent scatter radar sites ranging from the equator to the polar regions. The planned completion of a Polar Cap Observatory near the Earth's northern magnetic pole will strengthen the observational utility of this network.

Lower Atmospheric Processes

Societal vulnerability to extreme weather events demands continued improvement in knowledge that improves capabilities for predicting atmospheric and related environmental conditions on time scales ranging from minutes to centuries and geographic scales ranging from a few square kilometers to the Earth as a whole.

Much of the important research on lower atmospheric processes will be funded by disciplinary programs in atmospheric chemistry, physical meteorology, mesoscale dynamic meteorology, large-scale dynamic meteorology, and climate dynamics. These programs support research that increases knowledge and understanding about the physical, chemical and biological processes that define both the short term and long term atmospheric and environmental conditions. This knowledge base will be used with advanced computational and simulation technologies to improve spatial and temporal predictions of weather, climate, and other environmental conditions.

Numerous examples illustrate the advances that have been made in predictive capabilities. Over the last decade, the lead time for credible local weather forecasts has increased from four to five days to seven to nine days. Regional seasonal and annual forecasts of temperature and precipitation now are provided with an accuracy of 75percent or better. Forecasts of the location and timing of severe local weather events, such as flash floods or tornadoes, now are made six to twelve hours in advance. Predictions of regional and sub-regional long-term climate change and meaningful assessments of the impacts of such changes also have been improved.

These disciplinary programs have participated with partners elsewhere in NSF, in other agencies participating in the U.S. Global Change Research Program (US/GCRP), and in other nations in a set of focused global change programs like the Global Tropospheric Chemistry Program (GTCP) and the Climate Variability program (CLIVAR), which will continue during this planning period. A relatively new coordinated effort links GEO withNOAA, NASA, and the Office of Naval Research (ONR) in the conduct of the U.S. Weather Research Program (USWRP). The USWRP is a national research and technology-transfer program designed to develop the understanding, techniques, and systems necessary to translate basic scientific findings and new observational data into fundamentally improved short-term weather forecasts.

Infrastructural support for research on critical lower atmospheric processes includes the operation of aircraft and other observational platforms and dedicated computational facilities for analysis and modeling. Many of these facilities are operated by the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. GEO also has supported large-group research efforts focusing on lower atmospheric processes at the Center for the Analysis and Prediction of Storms (CAPS) at the University of Oklahoma and at the Center for Clouds, Chemistry, and Climate (C4) at the University of California-San Diego.

Land Surface Environmental Processes

The Earth's land surface is a zone of environmental interactions among the solid earth, the atmosphere, and a diverse array of plants, microorganisms, and animals, including humans. A better understanding of the complex processes at work in the surface environment is necessary in order to cope with world-wide problems of resource availability, including water, minerals, and energy resources; waste disposal; and other factors that influence the habitability of the Earth's surface.

Much of the research on the environmental processes operating on the Earth's land surface will continue to be supported by disciplinary programs that focus on geology and paleontology, hydrologic sciences, geophysics, and petrology and geochemistry. The integration of studies focusing on active processes, such as tectonic disruption, environmental change, erosion, and sedimentation, are leading to new understandings about the evolution and behavior of the Earth's land surface.

In addition to these disciplinary programs, a special competition linking GEO with other NSF units focuses on Environmental Geochemistry and Biogeochemistry (EGB) in order to enhance fundamental interdisciplinary research on chemical and biological processes that determine the behavior and distribution of inorganic and organic materials in environments at or near the Earth's surface. Another special competition that will continue into this planning period focuses on Water and Watersheds (WWS). The WWS initiative is co-sponsored by GEO, other NSF units, and the Environmental Protection Agency (EPA). Infrastructural support for research on Earth surface environmental processes will be provided through special awards for the development and acquisition of instruments and other equipment.

Crustal Dynamics

Enhanced knowledge about the movements of the Earth's crust is especially critical because of the wide-ranging impacts that crustal dynamics have on people and property around the globe. Research on crustal dynamics is supported by disciplinary programs that deal with tectonics, continental dynamics, geophysics, and marine geology and geophysics. Recent advances in these disciplines foreshadow exciting new insights that will be realized in the coming years. New techniques in thermochronology, for example, are being integrated with the analysis of cosmogenic nuclides, improved methods for radioisotope analysis, and cyclic and sequence stratigraphy to greatly improve the precision with which geologic phenomena are dated. Furthermore, integrated studies of the petrologic fabric of deformed rocks and minerals along with thermochronological studies are providing new insights into the mechanisms that form mountains.

Especially critical in the identification and analysis of crustal processes is the multinational Ocean Drilling Program, which continues to gather cores from sites around the world, develop new instruments for monitoring fluid flow, and provide research and training opportunities for thousands of scientists. The newly established International Continental Scientific Drilling Program is a comparable multinational effort designed to gather critical information about the continental crust. In order to stimulate special examinations of crustal dynamics, GEO will continue to sponsor a special emphasis area dealing with Active Tectonics, and support will continue for the Ridge Interdisciplinary Global Experiments (RIDGE) program, which focuses on understanding the causes and consequences of mass and energy transfers within the global ocean ridge system.

Critical infrastructure for research on Crustal Dynamics includes the Global Seismographic Network (GSN), a pool of portable seismographic instruments and a data-management system, all of which are operated by the Incorporated Research Institutions for Seismology (IRIS) with joint support from GEO and the U.S. Geological Survey (USGS). Crustal dynamics research is at the core of activities undertaken by the Southern California Earthquake Center (SCEC), which integrates scientific analyses of earthquake processes with the development of regional mitigation and response strategies for dealing with earthquake damage in major urban areas. SCEC is operated by a consortium of institutions led by the University of Southern California. In addition to NSF, the U.S. Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), and the state of California provide support for SCEC.

GEO Partnerships:
INDEPTH International Cooperation Provides New Information About Mountain-Building Processes

The collision of continents is one of the fundamental tectonic processes that forms mountain ranges. Evidence for continental collision is recorded in rocks as old as 3.5 billion years. Other evidence is found in the subduction of India beneath the Eurasian tectonic plate, a process that formed the Tibetan Plateau and Himalayas, the world's highest range. Recent GEO-supported studies in the Himalayas and Tibet have yielded some general insights into the formation of mountain ranges and the subsequent growth of the continental crust. U.S. and Chinese geoscientists have collaborated on the INDEPTH (International Deep Profiling of Tibet and the Himalaya) project, which has used advanced seismic imaging techniques to trace the active thrusting of India beneath Tibet along a transect extending about 220 km north from the Himalayan front. Combined seismic reflection profiling, wide angle reflection, broad band teleseismic studies using the IRIS portable arrays, and magnetotelluric surveys imply that the middle crust in this region is partially molten. The top of the partial melt zone is 15 to 18 km deep and is marked by seismic signals that suggest local magma accumulations at the top of the zone. These observations have allowed the U.S. and Chinese geoscientists to test hypotheses related to the sources of heat within the middle crust. Taken together, the INDEPTH observations imply that the partially molten middle crust in southern Tibet has acted like a fluid during the Himalayan collision, flowing to accommodate movements of both India and the Tibetan Plateau. By fostering international cooperation through INDEPTH, GEO has helped U.S. and Chinese geoscientists to gather and analyze information that increases knowledge about mountain-building processes in southern Asia and in other parts of the Earth.

Dynamics of the Earth's Interior

The dynamics of the mantle and core within the planet's interior have a profound impact on the way that the Earth functions. The "dynamo" in the core and the heat deep beneath the Earth's surface are the "engines" that power many solid-earth processes. Additional knowledge is needed on a range of processes, including the behavior of the Earth's magnetic field, interactions between the core and mantle, and the role of convection within the mantle on plate tectonic activity.

Disciplinary programs that will support much of the fundamental research on the dynamics of the Earth's interior include geophysics, petrology and geochemistry, continental dynamics, and marine geology and geophysics. Exciting breakthroughs have been made on a number of fronts related to improved understandings of the Earth's mantle and core. For the first time, seismic experiments over a mid-ocean ridge in the southern Pacific Ocean have identified the deep structure related to dynamics of the upper mantle that support sea-floor spreading. Recent supercomputer-based models of Earth's magnetic field have simulated Earth-like behavior within the core, including field reversals. These results have stimulated seismic studies that have confirmed that Earth's core rotates faster than the surrounding mantle and crust. For the first time, experiments replicating the intense pressures and temperatures of the lower mantle and core have yielded quantitative measurements of the physical properties of minerals and rocks. For example, innovative spectroscopic techniques have directly measured the physical properties of iron and light alloys at high temperature and pressure, thereby increasing knowledge about the likely physical and chemical state of the core.

Additional attention is given to this topic through the special interdisciplinary competition focusing on Cooperative Studies of the Earth's Deep Interior (CSEDI). Related research has been conducted by the Center for High-Pressure Research (CHiPR), which is operated by a consortium of institutions headed by the State University of New York-Stony Brook. CHiPR scientists have coordinated research on the use of high-pressure techniques to probe the properties and processes of the Earth's interior. They also have adapted new knowledge gained in these settings to the development of superhard materials, abrasives, and superconductors.

Physics and Chemistry of the Ocean

Physical and chemical processes operate at a variety of scales ranging from global patterns of ocean circulation to highly localized processes occurring at scales of a few kilometers or less. These processes are fundamental to the distribution of marine life, carbon flux, and local and global changes in the climate. Advancing knowledge about these processes improves our ability to understand and be prepared for changes in ocean conditions.

Much of the research focusing on these processes will be supported by disciplinary programs in physical and chemical oceanography. Research supported by GEO has helped reshape paradigms by analyzing the role of iron as a limiting resource in oceanic regions far from land. Much as the rudder affects the course of a ship, smaller-scale chemical mixing processes can affect ocean circulation, thereby influencing climatic patterns, the melting of ice in polar regions, sea levels, and biological distributions in upper ocean waters. New experiments designed to increase understanding of mixing will capitalize on advances made through the World Ocean Circulation Experiment (WOCE) and the Tropical Ocean/Global Atmosphere (TOGA) program.

GEO funding will help complete field observations and support analytic activities of special programs, such as WOCE and the Joint Global Ocean Flux Study (JGOFS), which GEO has co-sponsored with other US/GCRP agencies and with international partners. Essential infrastructural support for ocean process research is provided through GEO's support for the coordinated U.S. academic research fleet.

Marine Ecosystems

The distribution and abundance of marine organisms varies widely throughout the world's oceans. Whether through studies of processes affecting commercial fish stocks or through analyses of bacteria that can be used to mitigate the impact of pollution, increased knowledge about marine community dynamics provides valuable new insights of critical importance to people and industries.

The disciplinary program in biological oceanography will continue to support studies of relationships among marine organisms as well as interactions among these organisms and other facets of their geochemical and physical environments. GEO-supported research has examined the health of coral reefs and the processes that result in world-wide increases in harmful algal blooms. Building on these earlier studies, GEO is working with NOAA, EPA, and ONR to begin a long-term program designed to understand physical, chemical, and biological dynamics that lead to sudden coastal outbreaks of devastating coastal algae.

A special line of inquiry will be supported through the Global Ocean Ecosystems Dynamics (GLOBEC) program, which seeks to understand the role of physics in regulating populations of economic importance, including fish stocks. Another special initiative focusing on marine biotechnology aims to use marine systems to develop products and processes that have economic and environmental value. As is true for the study of chemical and physical ocean processes, GEO's support of the U.S. academic research fleet is essential for successful research on marine community dynamics.

Earth System Interactions

Although considerable attention can be focused on major components, the integrated character of the Earth system makes it essential to also examine the processes through which different components interact.

Interactions Between the Atmosphere and Land

Because people live in the zone where land surfaces and the atmosphere interact with each other, greater understanding of the nature of those interactions is of enormous benefit. Among the problems on which research can be expected to focus in the coming years are the impacts of volcanic activity on weather and climate, the influence of different land-surface features on local atmospheric patterns, and hydrologic responses to changing precipitation regimes.

Research on atmosphere-land interactions generally is interdisciplinary in character, and as such, it frequently will be supported through cooperative efforts of disciplinary programs dealing with different facets of meteorology, climate dynamics, geology and paleontology, and the hydrologic sciences. A special initiative addressing atmosphere-terrestrial interactions in the context of global change is the Water and Energy: Atmospheric, Vegetative, and Earth Interactions (WEAVE) program, which is jointly supported by GEO and the Directorate for Biological Sciences.

GEO Partnerships:

International Links Support the Lake Baikal Drilling Project

Lake Baikal is a sedimentary rift basin located in the central part of the Baikal Rift Zone in south-central Siberia, just north of the Russia-Mongolia border. Multichannel seismic profiling conducted through the collaboration of U.S., Russian, and other scientists indicates that sedimentary thickness exceeds 5 to 8 km in some parts of the Baikal basin. This lake-based geophysical work coupled with land-based structural studies has revealed important new information about the basin's history and seismic stratigraphy and about the paleoclimatic history of Asia.

The Baikal Drilling Project (BDP) began in 1989 as a joint U.S.-Russian scientific venture in cooperation with the NEDRA Drilling Enterprise of Yaroslavl, Russia. In subsequent years, Japan and Germany also provided support for the project. In January 1993, BDP geoscientists successfully deployed a lightweight drilling rig from a barge frozen into position in the southern part of the lake. With this system, hydraulic piston cores in excess of 100 m were successfully recovered from two holes in 354 m water depth. These cores provided climate data spanning the last 600,000 years. In early 1996, technological improvements made by NEDRA enabled drilling to a sub-bottom depth of 250 m, thereby providing data on climate change up to 4.5 million years ago. Through this GEO-sponsored international collaboration, BDP scientists are making major new contributions to the paleoclimatic and geologic history of Lake Baikal and south-central Siberia. BDP results are providing new evidence that Lake Baikal is highly sensitive to global land-atmosphere interactions and that the record of these interactions over the last several million years can be correlated with records of Earth system history from other locales around the globe.

Interactions Between the Atmosphere and Oceans

Recent advances in knowledge about physical and chemical atmosphere-ocean interactions and the adaptation of that new knowledge for purposes such as more accurate, longer-term forecasts of seasonal phenomena have demonstrated the utility of fundamental research on this critical set of interactions. Continued research will focus on interactions at a diverse set of geographic and temporal scales ranging from shorter-term regional variability over periods of months to global changes which will be evident over decades and centuries.

The dynamics of atmosphere-ocean interactions will continue to be a research emphasis for a number of disciplinary programs, especially climate dynamics and physical oceanography. These programs and counterpart units in other agencies participating in the US/GCRP will continue to support global change programs like the Climate Variability and Predictability program, which is building on the successful Tropical Ocean/Global Atmosphere program.

Earth System History

Considerable uncertainty remains regarding the variability and magnitude of future changes in the Earth's environmental systems. Considerable insight may be attained, however, by examining how and why climates and environmental systems have changed in the past. Research on Earth system history aims to understand the natural variability of the Earth system over millions of years and to increase knowledge about the nature of change within and among different physical and biological components of the Earth systems at a range of different temporal scales and at regional to global spatial scales.

GEO Partnerships:
International and Interagency Coordination Contribute to the Success of TOGA Program

The Earth's climate undergoes an irregular but recurring pattern associated with warm episodes of the El Niño-Southern Oscillation (ENSO) cycle. These episodes are characterized by extensive warming of the upper ocean in the tropical eastern Pacific associated with El Niño. The ENSO cycle produces the planet's largest short-term climate variability. The Tropical Oceans-Global Atmosphere (TOGA) program was designed to study seasonal-to-interannual climate variability and predictability, with an emphasis on ENSO. Before the ten-year-long TOGA Program, observing systems could not adequately recognize the warm phase of ENSO until it was well underway. At the conclusion of TOGA in 1995, a tropical Pacific observing network had been established. Skillful predictions of ENSO using data from this network were being used by governments on a number of continents to help critical economic sectors plan for climatic variations.

The implementation of TOGA was accomplished through the U.S. Global Change Research Program and was aided by an unusual set of institutional arrangements. U.S. participation in TOGA was coordinated by an interagency project office. Scientific advice was provided by the National Research Council through its TOGA Panel. Internationally, the program was administered by the International TOGA Project Office, advised by the TOGA Scientific Steering group, and supported through commitments made by an Intergovernmental TOGA Board. These management arrangements grew organically in response to the needs of the program and are credited with contributing to the successful operation of the program.

Research support by GEO and by other agencies has helped establish the framework of periods of extreme climate and episodes of rapid climate and ecological change. For example, continuing research conducted in coordination with NOAA emphasizes seasonal to annual time series in order to establish the full range of natural variability over thousands of years; the development and synthesis of large-scale terrestrial databases especially applicable for model testing; paleo aspects of Indo-Pacific circulation exchange and climate; and the use of continental drilling for the recovery and analysis of long, high-resolution sediment cores in regions fundamental for paleoenvironmental reconstruction.

GEO's Earth system history activities emphasize cooperative interdisciplinary research in answering critical global change questions. They are coordinated with other national efforts through the US/GCRP and with international efforts through the International Geosphere-Biosphere Programme. Many disciplinary programs in GEO support research on Earth system history, including programs that focus on paleoclimate, geology and paleontology, hydrologic sciences, geophysics, continental dynamics, marine geology and geophysics, and physical oceanography. These programs cooperate in a special interdisciplinary effort to facilitate research related to the use of Earth system history in answering critical global change questions. Additional contributions will be made by the Ocean Drilling Program and International Continental Scientific Drilling Program.

The Fully Coupled Earth Environment

The complex interplay of these different components constitute the heart of Earth system science, and a major objective of GEO's research efforts are to identify, analyze, and model the interactions among physical, chemical, geological, biological, and human processes on Earth at global, regional, and local scales. Earth system science provides a framework for integrating diverse sets of knowledge from many different disciplines to improve understandings about Earth's environment as a whole.

An important means for linking, testing, and applying existing and new knowledge is through development and refinement of interactive Earth system models that explicitly couple submodels that represent different components of the Earth system. Geoscientists and researchers in other fields have progressed from relatively simple coupled atmosphere-ocean models to highly sophisticated coupled models that link atmospheric, ocean, land-surface, and sea-ice submodels. A community-use climate model that represents complex physical and biogeochemical processes now is maintained at NCAR. This community-use model is used by a broad range of researchers for a diverse set of climate-sensitivity and predictive studies. The community-use climate model and other activities designed to advance understandings of the complex dynamics of the whole Earth system build on research sponsored by many different GEO programs as well as projects funded by other NSF units and other agencies. Special emphasis is given to this effort by the Climate Modeling, Analysis, and Prediction (CMAP) program, and infrastructural support is evident in the provision of advance scientific computational facilities at NCAR's Climate Simulation Lab.

Special Emphases Related to Earth System Processes and Interactions

Although much geoscience research focuses on the dynamics within and interactions among major components of the Earth system, a number of more focused research issues will receive special emphasis from GEO over the planning period.

Biotic Interactions with Physical Components of the Earth System

As new techniques for gathering and analyzing materials have been developed and used, previous assumptions about the processes that formed and altered different parts of the Earth system have been modified. For example, many geochemical processes that once were considered to be inorganic now appear to have been biologically mediated. Moreover, the identification of lifeforms in geothermal vents and other extreme locales has led to dramatic reconsideration of the conditions in which life may develop and evolve.

Research on biotic interactions with physical components of the Earth system will be supported by a number of different disciplinary programs in GEO, including ones focusing on biological oceanography, chemical oceanography, atmospheric chemistry, marine geology and geophysics, petrology and geochemistry, and geology and paleontology. Research on this issue also will be supported through the Environmental Geochemistry and Biogeochemistry competition and a new effort focusing on Life in Extreme Environments (LExEn). LExEn is organized by GEO and other NSF units and is coordinated with other agencies, including NASA. GEO-supported research will focus on explorations of life in a range of

GEO Partnerships:
Interdisciplinary Partnerships Focus Research on Life in Extreme Environments

Recent research in a broad range of different sites around the globe has provided new insight into the diverse range of environments where life forms exist. Explorations of the deep ocean floor along mid-ocean ridges has identified a rich set of microbial communities that thrive in hydrothermal environments where water circulation and chemical exchanges operate on massive scales. Aquifers and hydrothermal systems in the deep continental crust now are recognized as harboring microbial systems, with autotrophic bacterial communities documented in crystalline rocks at a depth of 1,500m. Diverse life forms also have been analyzed in polar settings, such as sea ice, polar deserts, and isolated lakes in Antarctica's dry valleys.

These new findings have highlighted the need for interdisciplinary exploration of the complex interactions between biotic and physical systems. To further stimulate the integration of research efforts by scientists from many different disciplines, GEO is working with the NSF Biological Sciences, Engineering, and Mathematical and Physical Sciences directorates and with the Office of Polar Programs to develop and operate an integrated interdisciplinary research effort focusing on Life in Extreme Environments. Formally initiated in FY 1997, LExEn seeks to improve fundamental understanding of the formation and development of life and to increase knowledge about the physical, chemical, and geological processes that sustain life. The study of microbial life forms that exist in extreme conditions on Earth, ranging from volcanoes to hydrothermal vents on the ocean floor to polar sea ice, will provide important new insights about how life originated and evolved on Earth and whether and how life may exist on other planets.

extreme environments on Earth, including the presence of large microbial masses living in the solid earth beneath the ocean.

Natural Hazard Reduction

Although the physical components of the Earth system sustain people, they also can pose threats to life and property. Catastrophic events like volcanic eruptions, earthquakes, tidal waves, floods, hurricanes, tornadoes, and other kinds of severe storms in the lower and upper atmosphere can do considerable damage, as can longer-duration phenomena like droughts and harmful algal blooms. Through improved understanding of the processes that result in these kinds of events, more advanced warning can be given before hazardous events occur, response systems to mitigate damage associated with these events can be improved, and people can learn how to alter their behavior to minimize the damage.

Many GEO disciplinary programs support research on Earth system dynamics associated with natural hazards both independently and through cooperative efforts to address different types of hazardous phenomena. The NSWP addresses hazards associated with solar storms and other disruptive events in the upper atmosphere. The USWRP focuses on developing the meteorological knowledge and the mathematical and computational techniques needed to better predict atmosphere dynamics. Improvements are expected in the identification of critical factors that influence hurricane tracks and intensities and in the incorporation of these factors into numerical models that predict hurricane behavior. GEO participates with other NSF units and other federal agencies in the National Earthquake Hazard Reduction Program (NEHRP).

The breadth of GEO's interest inaddressing natural hazards associated with physical components of the Earth system also is evident in major infrastructure investments. Examples are the Global Seismographic Network, which is designed to improve understandings of the processes that produce earthquakes, and the Center for the Analysis and Prediction of Storms and the Southern California Earthquake Center, two science and technology centers that have contributed to society's capabilities to reduce the hazards associated with extreme natural phenomena.

Coastal Environmental Processes

Coastal regions are important areas for study by geoscientists, because they are the location where atmospheric, ocean, and terrestrial components of the Earth system all interact. Achieving greater knowledge about the processes at work in coastal environments is even more important, however, when one realizes that an increasingly large share of the world's people live along or near coastlines. Coastal realms also are important because they are the location of most of the world's fisheries, they account for a considerable share of the world's biological production, they are the primary locale for accumulation of sediments, and they are critical zones of atmospheric transition.

A diverse set of GEO disciplinary programs in the atmosphere, solid-earth, and ocean sciences support research that examines processes and interactions within coastal zones. A number of initiatives place special emphasis on research in the coastal realm, including the Coastal Ocean Processes (CoOP) program, which seeks to improve quantitative understanding of the processes that dominate the transport, transformations, and fates of materials within coastal systems. CoOP is co-sponsored by GEO, NOAA, and ONR. Another special emphasis activity is the Continental Margins (MARGINS) program, which aims to understand the complex systems that maintain and modify the boundary zone between continents and oceans. In a third initiative, GEO and NOAA will support interdisciplinary studies of coastal dynamics in the Great Lakes.

In order to provide infrastructural support, GEO and its institutional and agency partners will explore possibilities for refitting current vessels or constructing one or more new ships for research on coastal environmental processes. In cooperation with the NSF Directorate for Biological Sciences, GEO will reorganize the network of coastal monitoring sites by merging Land Margin Ecosystem Program (LMER) sites into the Long-Term Ecological Research (LTER) network.

III. HIGH-PRIORITY INFRASTRUCTURAL INVESTMENTS

The nature of geoscience research requires large investments to be made in facilities and instruments as well as other forms of infrastructure. Many field projects supported by GEO require significant capital investments in order to study complex, interdependent processes extending over large areas. Decisions regarding GEO's support for science and technology centers, facilities, equipment, instrumentation, and other forms of infrastructure are made in concert with the development of scientific research priorities. They also are made in coordination with other federal agencies, industrial organizations, and international partners.

Atmospheric Facilities

Previous discussions of major scientific themes have identified a number of GEO's infrastructural investments. Within the atmospheric sciences, support will continue for the National Center for Atmospheric Research. Among the critical facilities provided by NCAR are state-of-the-art computational facilities used for modeling atmospheric and ocean phenomena and a broad range of observational platforms, including Doppler weather radar units, research aircraft, and surface observing systems. GEO also will continue to support upper atmospheric facilities, particularly a network of incoherent scatter radar facilities in the Western Hemisphere that complements counterpart facilities in the Eastern Hemisphere maintained by European nations and Japan.

To further facilitate upper atmospheric research, GEO plans to pursue construction during this planning period of a Polar Cap Observatory (PCO) near the Earth's northern magnetic pole in northern Canada. The PCO will be designed to obtain ground-level measurements of the "solar wind," which consists of charged particles that are energized in space and that enter the atmosphere and deposit energy, producing auroras and modifying the composition of the ionosphere and neutral atmosphere.

GEO also is planning, in conjunction with NCAR and the university community, for the acquisition, modification, and outfitting of a modern, mid-sized, high-altitude jet aircraft. This new high-altitude research platform will significantly advance national capabilities for the conduct of science, providing measurement access over the entire globe for NSF's climate, weather, and related research programs.

Shared-user resources in the atmospheric sciences will be maintained at levels comparable to those of the mid-1990s during the period from FY1998 to FY 2002. The facilities, equipment, and computers at the National Center for Atmospheric Research and the existing incoherent scatter radar facilities play critical roles in the conduct of a wide range of atmospheric science inquiries, and as a result, support for these facilities will be kept in balance with the support for activities undertaken through research projects. Other atmospheric facilities, including aircraft and related ground-based support facilities managed by NCAR and universities, also will be maintained, with upgrades undertaken as feasible in conjunction with normal maintenance.

Solid-Earth Science Facilities

GEO will continue to support the IRIS facilities for seismology, which consist of the Global Seismographic Network of permanent stations, a pool of portable seismographs, and a data-management system. These facilities support basic research in earthquake studies, imaging of the Earth's internal structure and dynamics, and nuclear test-ban monitoring. GEO also will maintain support for other multi-user facilities that provide access to expensive technologies, such as the Consortium for Advanced Radiation Sources (GeoCARS) synchrotron X-ray beamlines at the Advanced Photon Source, facilities for accelerator mass spectrometry (AMS) and large ion microprobe systems at the University of Arizona and Purdue University, and the University Navstar Consortium (UNAVCO) facility for Global Positioning System (GPS) geodesy.

Through advanced facilities like these, geoscientists are able for the first time ever to monitor changes in the Earth's crust on temporal and spatial scales comparable to the rates at which geological processes occur. Linked arrays of GPS receivers, seismographs, and strain gauges coupled with the synoptic ability of satellite radar interferometry will constitute geophysical observing systems that allow the real-time monitoring of how the Earth behaves. Databases produced by these geophysical observing systems will allow analytical tests of dynamic models of solid-earth processes comparable to analyses of atmospheric and oceanic processes.

Academic Research Fleet and Other Ocean Science Facilities

The U.S. academic research fleet is an integral component of ocean science research supported by GEO and other federal agencies, often in conjunction with international partners. Support for maintenance and operation of the academic research fleet of more than two dozen vessels will be maintained at levels that will enable scientific needs to be met. Upgrades and replacement of vessels may be undertaken in conjunction with the lay-up of vessels during parts of the planning period. Refitting of the ODP drillship, the *JOIDES Resolution*, also will be undertaken during this period in order to permit it to continue to provide essential support for this important program.

The launching by the U.S. Coast Guard in the late 1990s of a research vessel providing all-season access to the Arctic Ocean and nearby seas will expand capabilities for research in this critical region. GEO and other units in NSF will continue to work with researchers and with the Coast Guard and other agencies to develop and implement a research strategy for the region using this new facility.

New kinds of ocean science facilities will be explored during the period from FY 1998 to FY 2002. Shared-use facilities for data analysis and modeling of physical, chemical, and biological ocean processes would take advantage of new architectures for distributed information management, thereby facilitating both the advancement of ocean science research and the exploration of new technologies for enhancing knowledge and distributed intelligence. In a similar way, advanced technologies will be used to develop and test sea-floor observatories, which will gather critical data about conditions on and near the ocean floor.

Integrated Systems for Monitoring and Analyzing Earth System Dynamics

Although much new knowledge about the Earth system results from the aggregated efforts of thousands of highly capable scientists using proven techniques to gather and analyze information, a significant number of advances occur because new methods and techniques offer innovative approaches for addressing critical issues. The recent development of new technologies for gathering, analyzing, and disseminating information about the Earth system and for facilitating communication among scientists highlight opportunities for further advancing geoscience research in the near future.

New technologies have greatly expanded the range, quality, and timeliness of information that can be gathered and used by geoscientists to monitor activity within different components of the Earth system. In a similar way, dramatic improvements in computational capabilities have greatly increased the speed and power of analyses that geoscientists can perform. Information exchange and scholarly communication has been facilitated by advances in telecommunications capabilities, especially the wide-spread adoption and use of the Internet both for focused information exchange via electronic mail and wide-spread dissemination of material over the World Wide Web. These developments have transformed the ways in which geoscientists operate, and comparable advances in technology undoubtedly will have equally profound impacts on scientific capabilities in the future.

GEO has supported the development, adoption, and use of these new technologies through individual actions taken by disciplinary programs. The Ocean Technology Program, for example, supports the use of fiber optic links to transmit real-time data from coastal ocean observatories. GEO also has advanced the use of new technologies through wider-ranging efforts, such as the establishment of the GSN and related IRIS facilities and support for the University Navstar Consortium, a cooperative effort of more than 30 universities that use the Global Positioning System for research on a diverse set of geoscience issues.

Over the planning period covered by this plan, GEO expects to expand its efforts in cooperation with public and private-sector partners to advance the use of geographic information systems (GISs) and other new technologies that can be used for integrated analyses of Earth system processes. Special attention will be given to increasing interoperability among different systems and data sources. The objective of this effort will be to provide transparent, platform-independent access to distributed resources for researchers and others. GEO activities in this area will be coordinated with the efforts of other NSF units through the foundation-wide Knowledge and Distributed Intelligence (KDI) effort. GEO also intends to explore the adaptation of new technologies for use in new monitoring and data-management systems, including the development of sea-floor observatories and shared-use facilities for data analysis and modeling in the ocean sciences.

GEO Partnerships:

Industrial and Interagency Partnerships Take Advantage of the Global Positioning System

The first Global Positioning System (GPS) tracking network was established two decades ago by the U.S. Department of Defense. More recently, civilian organizations from a number of nations have established the International GPS Service network, which includes more than 50 globally distributed tracking stations in support of geodetic and geophysical research activities.

The GPS has revolutionized many lines of geoscience research. Scientists at the Southern California Earthquake Center (SCEC) have been using GPS to obtain extremely precise geodetic measurements that monitor the changing regional crustal strain in southern California. By placing GPS receiving stations at selected sites throughout the region, SCEC scientists have been able to measure small vertical and horizontal movements, thereby improving analysis of how crustal strain is proportioned in the crust. An important new insight gained from these analyses is that significant non-seismic slip occurs along fault lines. These “stealth earthquakes” apparently occur after major earthquakes, such as the 1992 Landers earthquake (magnitude 7.5) and the 1994 Northridge earthquake (magnitude 6.7). GPS-related analyses also have identified high strain rates focused near the sites of major historic earthquakes, perhaps indicating that the elastic failure associated with major earthquakes is followed by visco-elastic recovery of the lower crust. Because GPS-based information has been so valuable, SCEC geoscientists now are installing a dense network of up to 250 permanent GPS stations in the region. Support for installation of this network was provided by NSF’s Advanced Research Infrastructure program, the USGS, NASA, and the W.M. Keck Foundation.

The potential for GPS to contribute to atmospheric research also is becoming apparent. While passing through the atmosphere, GPS radio signals are slowed and bent in response to changes in atmospheric structure. For the geologist, this "noise" degrades the accuracy of the terrestrial measurements. But the geologist's "noise" is valuable information for the atmospheric scientist. As a result, NSF has supported the GPS Meteorology (GPS-MET) project, a proof-of-concept experiment using GPS signals to gather atmospheric data.

On April 3, 1995, Orbital Sciences Corporation placed a MicroLab-1 satellite in low Earth orbit. Circling the Earth every 100 minutes, the satellite carries a radio receiver that receives signals from the constellation of GPS satellites. The data collected from this receiver is the basis for a proof-of-concept experiment to test whether GPS radio signals can provide accurate, high-resolution, three-dimensional estimates of atmospheric temperature, water vapor, and ionospheric electron densities. Initial results for temperature profiles between about 5 km and 40 km in altitude are excellent, with accuracy better than 1 degree K. Water vapor accuracy below 5 km is better than 10 percent, provided temperature is known to within 2 degrees K. Ongoing research is addressing regions above 40 km and below 5 km. The ionospheric data have been excellent and are producing useful ionospheric electron density profiles.

Support for GPS-MET has been provided through a partnership that includes GEO, the Federal Aviation Administration (FAA), NOAA, NASA’s Jet Propulsion Lab (JPL), Orbital Sciences Corporation, and Allen Osborne

Associates. Project scientists from UCAR's University Navstar Consortium collaborate with scientists from NCAR, the University of Arizona, and JPL. GPS-MET provides global coverage at high vertical resolution in all weather conditions and is self-calibrating. This technology is gaining wide recognition as a strong candidate for a new, low-cost operational observing system in support of weather prediction, climate change detection and research, and ionospheric studies. Based on this proof-of-concept project, discussions now are underway among the GPS-MET partners and organizations from a number of other nations to establish a constellation of about ten GPS-MET satellites, which would yield approximately 5,000 soundings a day with vertical resolution of about 1 km and horizontal resolution of about 300 km.

IV. HIGH-PRIORITY RESEARCH-BASED EDUCATIONAL ACTIVITIES

Geoscience education contributes to a higher degree of scientific understanding among the general population, and it ensures that knowledgeable and skilled individuals will be able to assume positions as productive geoscientists in the future. Geoscience education therefore is an investment in the future of the nation as well as in the future of the geosciences themselves. GEO has and will continue to focus much of its attention on high-quality fundamental research to advance knowledge about the Earth system, but the need for improvement in geoscience education has become more apparent in recent years. As a result, GEO will place greater emphasis on educational efforts in which it can play an especially significant role.

Many of GEO's research awards include support for educational activities through the support of undergraduate and graduate students and postdoctoral fellows. GEO will continue to provide this critical support, emphasizing the need to improve the quality of the educational experience for those individuals who have chosen to pursue careers in the geosciences. Greater emphasis also will be given to assisting high-quality students in pursuing geoscience careers beyond academia.

Some GEO awards also result in the broader dissemination of research results beyond standard scholarly outlets. GEO will continue to support these kinds of activities, but it also will address needs in other educational realms. Working with other NSF units, especially programs in the Directorate for Education and Human Resources, and with external partners ranging from other federal agencies to university consortia, professional societies, and private-sector firms, GEO will pursue a catalytic role in the reform of science education in pre-collegiate and non-classroom settings.

Numerous opportunities exist for improvement in geoscience education in these settings. The geosciences provide a natural window on the world of science. Nearly every child displays a healthy curiosity about the Earth, and the dynamic character of the solid earth, atmosphere, and oceans provide numerous opportunities for discovery and personal growth. Enhancements in geoscience education can have profound impacts on people both in pre-collegiate classroom environments and in informal science educational settings, including museums and science centers as well as film, television, and video. Increased use of compact discs and other forms of multi-media offer potentially productive outlets for effective education about the Earth that we inhabit.

GEO also will work toward improving geoscience education in collegiate settings. Enhancement of undergraduate courses dealing with the geosciences should expose a wide range of students to scientific principles and practice through discovery- and inquiry-based learning. These efforts will emphasize the utility of the conceptual, observational, and analytic skills associated with the geosciences as part of a solid foundation for many careers, including education and public service. Because the job market for geoscientists is changing rapidly, education and training at graduate and postdoctoral levels will emphasize development of sound intellectual and technical foundations for pursuit of a diverse set of careers where fundamental knowledge based in the geosciences will prove useful. Improvements in geoscience education also should attract more women and individuals from underrepresented ethnic and racial groups to pursue careers in the geosciences, thereby increasing diversity within the geoscience community.

Starting with this planning period, GEO is placing increased emphasis on improvements in geoscience education. The Advisory Committee for Geosciences is working with GEO to identify needs and opportunities and to analyze alternative approaches. A major workshop in August 1996 brought together leading geoscience researchers and educators from a variety of organizational settings around the nation. Outlined in the following paragraphs as some of the most promising ways identified for GEO to contribute to the integration of research and education and to improvements in geoscience education.

Assistance in the Formation of Collaborative Teams of Researchers and Educators

By highlighting geoscience education as a high priority, GEO expects to encourage many geoscientists who are naturally inclined to want to pursue educational activities to do so. GEO staff will work with counterparts in the NSF Directorate for Education and Human Resources to better inform geoscientists about opportunities for support of innovative geoscience educational activities. Because experience has demonstrated that some of the most significant advances in education occur when research scientists work together on collaborative teams with teachers and other educators, GEO will work to facilitate the formation of these collaborations. Among the strategies that will be explored for providing such assistance are supplements to research awards that support education-related, team-building efforts and awards that will enable teachers and other educators to spend time working on projects and at major facilities with geoscience researchers. GEO also will promote the development of educational alliances among researchers and educators in the many university-level consortia that it supports, and it will explore potentials for working with professional societies that share its goals for improved geoscience education.

Focused Programs to Improve Training for a Diverse Range of Geoscience Careers and for Increasing Diversity in the Geosciences

In a similar way, GEO will work with other NSF units and other organizations to enhance the quality of instruction and the practical experience of individuals interested in pursuing geoscience-related careers. GEO will participate in an NSF-wide activity to support integrated graduate education and research training that will focus on interdisciplinary topics and facilitate the development of innovation and flexibility in the individuals who receive support. GEO will seek to expand and broaden opportunities for undergraduate research experiences through a number of means, including the direct involvement of students on active research teams, increased access for broadly based educational purposes to GEO-supported research facilities, and development of state-of-the-art computer-based teaching labs tailored expressly for the geosciences.

In these and other activities, GEO will increase its efforts to correct the underrepresentation of women and minorities in the geosciences by encouraging their active participation in educational and related programs. GEO will maintain support for special Research Experiences for Undergraduate (REU) Site activities that have assisted underrepresented groups. GEO will expand its support for diversity-enhancing activities at science and technology centers, and it will increase its support for focused activities designed to provide students from underrepresented groups with opportunities to learn about and participate in geoscience research. GEO also will build on its involvement in the Model Institutions for Excellence (MIE) Program, which includes an award to the Universidad Metropolitana of Puerto Rico.

V. ACTIVITIES TO BE SUPPORTED WHEN ADDITIONAL RESOURCES BECOME AVAILABLE

The previous three sections of this science plan have described those activities that GEO plans to give high priority for support during the period from FY1998 to FY 2002. The activities underscored in those sections should not be considered as the only geoscience activities worthy of support during the planning period, however. Through the GEO long-range planning process, the following activities and infrastructural investments have been identified as meritorious, but because of higher costs associated with these activities, they cannot be pursued completely until additional resources become available. This section describes some of the high-priority activities that should be supported when additional resources become available, whether through changes in the amount of funding that becomes available for GEO or through increased levels of financial and in-kind support from other organizational partners.

Expansion of Rapidly Developing Research Areas

During the period from FY1998 to FY 2002, GEO will strive to support all important lines of geoscience research that are likely to emerge during that period. History has shown, however, that a number of areas are likely to see greater than expected activity because of the significance of the topics and of new discoveries in those areas. These forces will lead to increased pressures for research support beyond the levels anticipate at this stage in the planning process. Through its ongoing proposal review process and through continued attention to long-range planning, GEO will work to maintain proper levels of support across all fields. The need to maintain flexibility will be especially great in those areas where GEO will work with other partners to support rapidly developing lines of inquiry. Life in Extreme Environments is one example of a research effort for which additional support beyond currently anticipated levels may be needed, with other possible candidates found in other scientific issue areas identified in the second section of this plan.

Enhancement of International Cooperative Research Programs

U.S. leadership in major international cooperative research programs, including a number of core projects of the International Geosphere-Biosphere Programme and the World Climate Research Programme, focuses special attention on the need for maintenance or expansion of GEO support for collaborative efforts linking U.S. and foreign scientists. The next generation of the Ocean Drilling Program likely will require expanded and improved capabilities that can be provided only with additional resources. In a similar way, the International Continental Scientific Drilling Program probably will require enhanced support if it is to take maximum advantage of the collaborative research possibilities associated with this new program.

Upgrades of Atmospheric Science Infrastructure

Advances in atmospheric science research on a number of topics have highlighted the need for expansion of facilities and equipment on which future research activities will rely. Upgrades and replacements of aircraft that take critical measurements of atmospheric phenomena operating at scales ranging from the local to global are warranted. These kinds of investments have been especially effective in recent years, as GEO funding for these airborne platforms has focused on the marginal costs of upgrading excess military aircraft made available by the Department of Defense. GEO intends to use advisory panels during the planning period to determine the composition and capabilities of lower atmospheric science facilities. Additional support also would be warranted for further expansion of computational capabilities at NCAR and for modernization of building systems at the NCAR Mesa Laboratory.

Construction or Upgrade of Academic Research Fleet Vessels and Development of New Ocean Science Facilities

GEO anticipates that requirements for the academic research fleet that supports ocean-based research can be met over the period from FY1998 to FY 2002 through maintenance of the current budget for the academic fleet, but the need for additional support for new vessels and major upgrades will increase throughout the planning period. Construction of a coastal research vessel has been proposed to provide adequate facilities for measurements, experiments, and over-the-side operations that currently are not available on ships used for coastal research. Additional support also would permit full development of a network of sea-floor observatories to gather information about physical, chemical, and biological characteristics of the ocean floor.

Enhancement of Geoscience Educational Activities

As GEO explores the ways that it can play a positive role in the enhancement of geoscience education at all levels, opportunities are expected to arise that will allow GEO to work with partners in a variety of productive ways. As with research and infrastructure, GEO will remain flexible in its approach in order to respond to some of the most promising opportunities. Among the activities for which GEO and its educational partners may seek increased support is research focusing on the processes through which geoscience education occurs, including cognitive research focusing on the thinking and problem-solving skills used by geoscientists. Research on geoscience education may prove to be critical in helping implement the National Science Education Standards and in reforming undergraduate curricula in the geosciences. Another potentially promising thrust for which GEO would work closely with appropriate partners is the establishment of state-of-the-art geoscience programs in a number of institutions with predominantly minority enrollments, thereby providing a new track for broadening the range of settings where high-quality geoscience education is available for all students and for increasing diversity among active geoscientists.

GLOSSARY OF ACRONYMS

Acronym	*Full name or term*
AMS	accelerator mass spectrometry
BDP	Baikal Drilling Project
C4	Center for Clouds, Chemistry, and Climate; University of California-San Diego
CAPS	Center for the Analysis and Prediction of Storms; University of Oklahoma
CHiPR	Center for High-Pressure Research; State University of New York-Stony Brook
CLIVAR	Climate Variability program
CMAP	Climate Modeling, Analysis, and Prediction program
CoOP	Coastal Ocean Processes program
CSEDI	Cooperative Studies of the Earth's Deep Interior program
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
EGB	Environmental Geochemistry and Biogeochemistry competition
ENSO	El Niño-Southern Oscillation
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration, Department of Transportation
FEMA	Federal Emergency Management Agency
GTCP	Global Tropospheric Chemistry Program
GEO	Directorate for Geosciences; National Science Foundation
GeoCARS	Consortium for Advanced Radiation Sources
GISs	geographic information systems
GLOBEC	Global Ocean Ecosystems Dynamics program
GPRA	Government Performance and Results Act
GPS	Global Positioning System
GPS-MET	GPS Meteorology project
GSN	Global Seismographic Network
IAI	Inter-American Institute for Global Change Research
ICDP	International Continental Scientific Drilling Program
IGBP	International Geosphere-Biosphere Programme
INDEPTH	International Deep Profiling of Tibet and the Himalaya project
IRIS	Incorporated Research Institutions for Seismology
JGOFS	Joint Global Ocean Flux Study
JPL	Jet Propulsion Laboratory
KDI	Knowledge and Distributed Intelligence initiative
LExEn	Life in Extreme Environments initiative
LMER	Land Margin Ecosystem Program
LTER	Long-Term Ecological Research network of observational sites
MARGINS	Continental Margins program
MIE	Model Institutions for Excellence program
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NEHRP	National Earthquake Hazard Reduction Program
NOAA	National Oceanic and Atmospheric Administration, Department of Commerce

Acronym	*Full name or term*
NSF	National Science Foundation
NSWP	National Space Weather Program
ODP	Ocean Drilling Program
ONR	Office of Naval Research, Department of Defense
PCO	Polar Cap Observatory
REU	Research Experiences for Undergraduates program
RIDGE	Ridge Interdisciplinary Global Experiments program
SCEC	Southern California Earthquake Center; University of Southern California
TOGA	Tropical Ocean/Global Atmosphere program
UNAVCO	University Navstar Consortium
US/GCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey, Department of Interior
USWRP	U.S. Weather Research Program
WCRP	World Climate Research Programme
WEAVE	Water and Energy: Atmospheric, Vegetative, and Earth Interactions program
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WWS	Water and Watersheds competition